Data Applicability of Heritage and New Hardware For Launch Vehicle Reliability Models

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Purpose

- Bayesian reliability requires the development of a prior distribution to represent degree of belief about the value of a parameter (such as a component's failure rate) before system specific data become available from testing or operations.
  - Generic failure data are often provided in reliability databases as point estimates (mean or median)
  - A component's failure rate is considered a random variable where all possible values are represented by a probability distribution
  - The applicability of the generic data source is a significant source of uncertainty that affects the spread of the distribution.

This presentation discusses heuristic guidelines for quantifying uncertainty due to generic data applicability when developing prior distributions mainly from reliability predictions.

Uncertainty

- Uncertainty is represented as a probability distribution for a parameter, such the failure rate of a component

- Understanding the sources of uncertainty, how to estimate it, and methods for reducing it support better decision making
  - Design and Development of Complex Launch Vehicles
  - Launch Readiness Decisions
  - Scenario and System Trade Studies

Background on Uncertainty

- Two types of uncertainty
  - Aleatory (inherent physical random variability)
    - Typically inherent in every system and cannot be reduced
  - Epistemic (lack of knowledge or ignorance)
    - Can be reduced by increasing knowledge
- Epistemic uncertainty includes:
  - Completeness (missing scope/scenarios)
  - Parameter (component/subsystem)
  - Model (assumptions, system treatment)
- This presentation will focus on epistemic uncertainty associated with the parameters of reliability models

Parameter Data Sources and the Concern of Applicability

- New Launch vehicles (LV) comprise heritage and new hardware
- Generic reliability data are collected from a wide spectrum of sources:
  - Component databases (NPRD, EPRD, NUCLARR, etc.)
  - Aerospace historical data
  - Other industry historical data
  - Piece part count method (MIL-HDBK-217F)
  - Engineering judgment
- This variety of data sources raises the concern of source data applicability to target parameter

What is Data Applicability and why is it important

- Applicability is the degree of credibility and relevance of the source data
- Data applicability is a significant source of epistemic uncertainty
- Bayesian methods permit the use of subjective information, and a heuristic approach is one way to consistently incorporate subjective judgments about applicability into the modeling process
- The evaluation of applicability with a heuristic approach is most useful
  - When other Bayesian statistical methods are not available or yield poor results
  - To ensure consistent judgments throughout the model

An approach for quantifying data applicability

- Classify the applicability of the reliability data source
- Assess the environmental conditions between the source and the target parameter
- Apply the appropriate K factor (Logistic Performance Factors) to adjust the source data mean from its environment to predict the mean failure rate of the component in the application environment
- For each data source, apply the heuristic guidelines to quantify the uncertainty due to applicability
- Source applicability is divided into two categories
  - Data source application
    - Rank most applicable to least applicable data sources
  - Data source environment
    - Uncertainty increases when converting from one type of environment to another (i.e., GF to AUF, or AUF to AIF)

Data Source Classification Table for Heritage Hardware

Source Category	Source Descrption	Source Application	Source Application Error Factor	Compatible Environment	Adjusted Environment
Historical	Specific Component Data	different LV -same component	3	No impact on Error Factor	Increases the Error Factor
		different LV - like component	4		
	Aerospace Data	Same LV component	5		
		Like component	6		
	Other Industry Data	Same LV component	6		
		Like component	7		

Note: The error factor (EF) is a measure of dispersion of the lognormal distribution.

- EF = 95^{th}/Median = Median/5^{th} = sqrt(95^{th}/5^{th})
- An EF of 1 is certainty (point estimate)

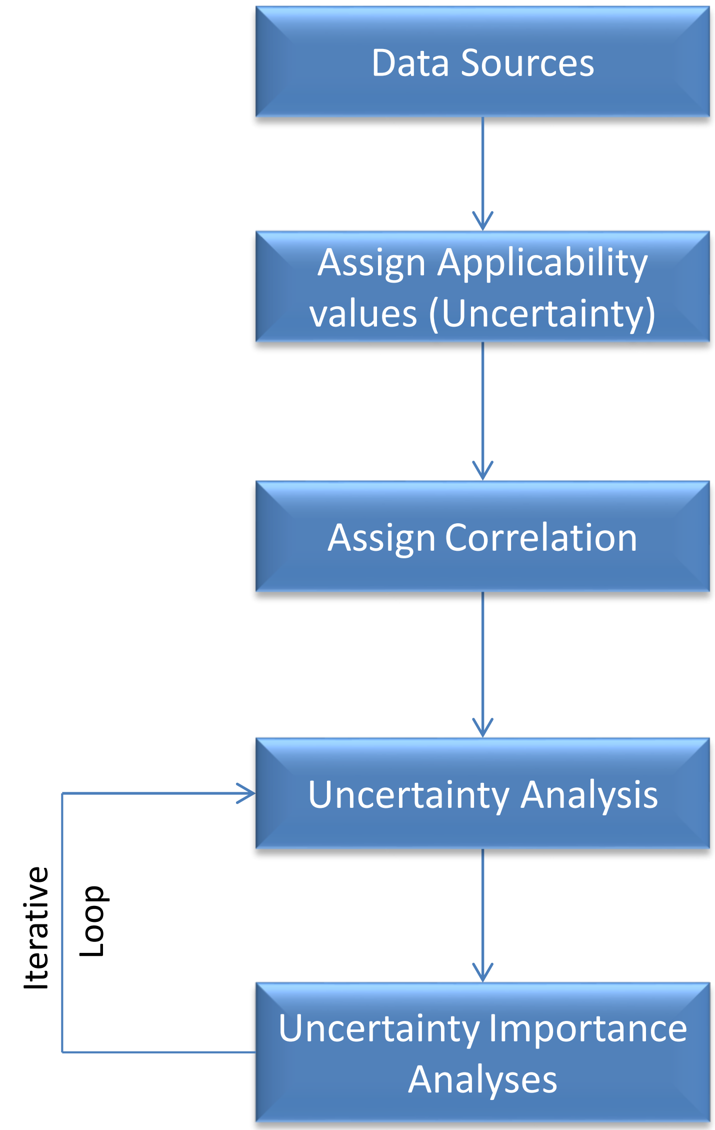
Data Source Classification Table for New Hardware

Source Category	Source Descrption	Source Application	Source Error Factor	Compatible Environment	Adjusted Environment
Prediction	PiecePart Method	Same LV component	8	No impact on Error Factor	Increases the Error Factor
		Like component	9		
	Non-expert Engineering Judgement	Documented Process	10		
		Documented/Undocumented Process	15		

Data Source Classification Approach
The complete Table

Source Category	Source Descrption	Source Application	Source Application Error Factor	Compatible Environment	Adjusted Environment
	Specific Component Data (Most Applicable)	different LV -same component	3	No impact on Error Factor	Increases the Error Factor
		different LV - like component	4		
	Aerospace Data	Same LV component	5		
		Like component	6		
	Other Industry Data	Same LV component	6		
		Like component	7		
Prediction	PiecePart Method	Same LV component	8		
		Like component	9		
	Non-expert Engineering Judgement (Least Applicable)	Documented Process	10		
		Undocumented Process	15		

Process to Reduce Uncertainty



Collect failure rate data for the components

Assign lognormal prior distributions to failure rates by selecting the appropriate error factor for each unique reliability block

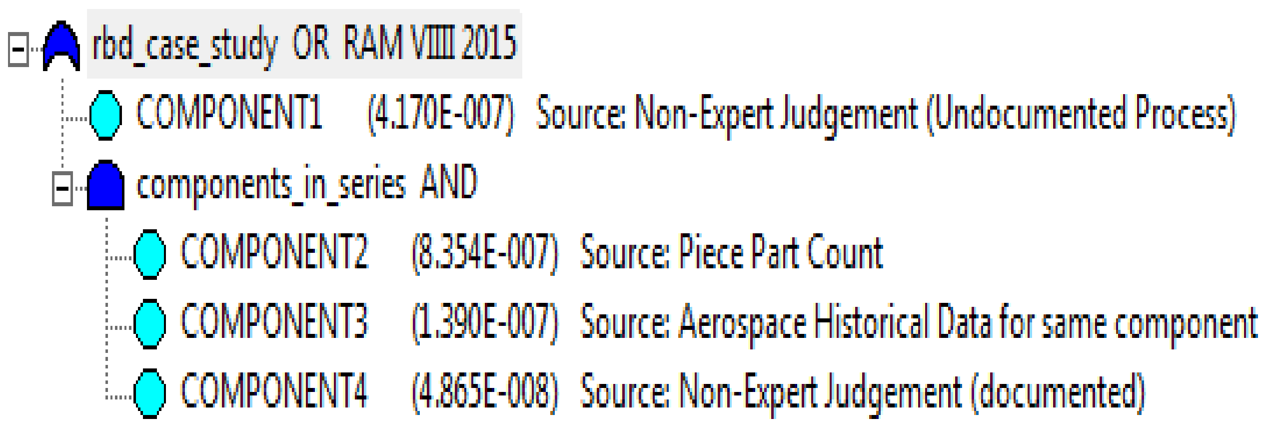
Correlate reliability blocks

Run uncertainty analyses (i.e., MC)

Run uncertainty importance analyses and determine which blocks drive the lower and upper bounds

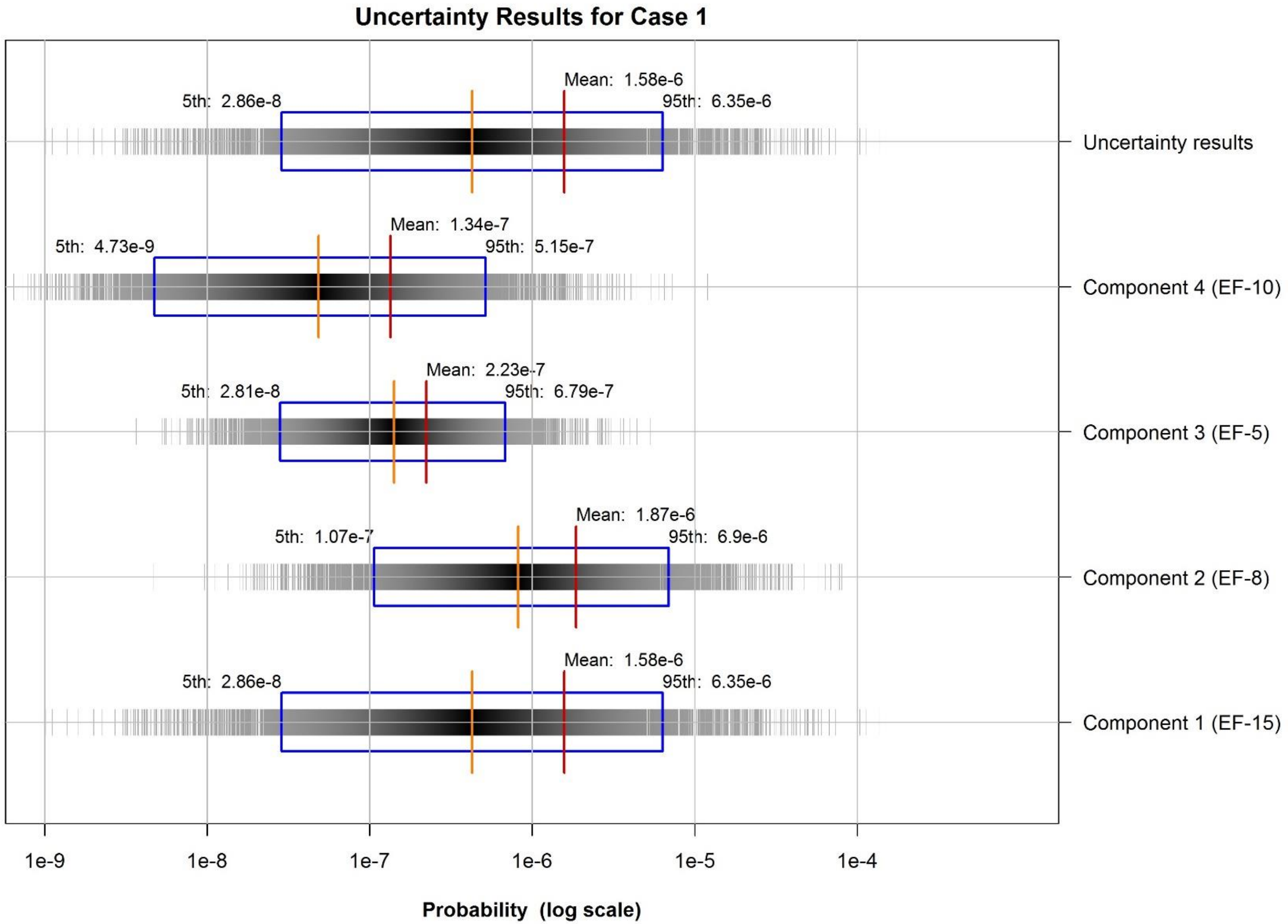
Case Study
Simple Fault Tree

- A simple model consists of 4 components 1, 2, 3 and 4
- Component 1 is in parallel with components 2, 3, and 4
- Components 2, 3, and 4 are connected in a series configuration



Note: Numbers shown on this slide are examples only and do not represent data from NASA systems

Case Study
Uncertainty Quantification Results
Run1



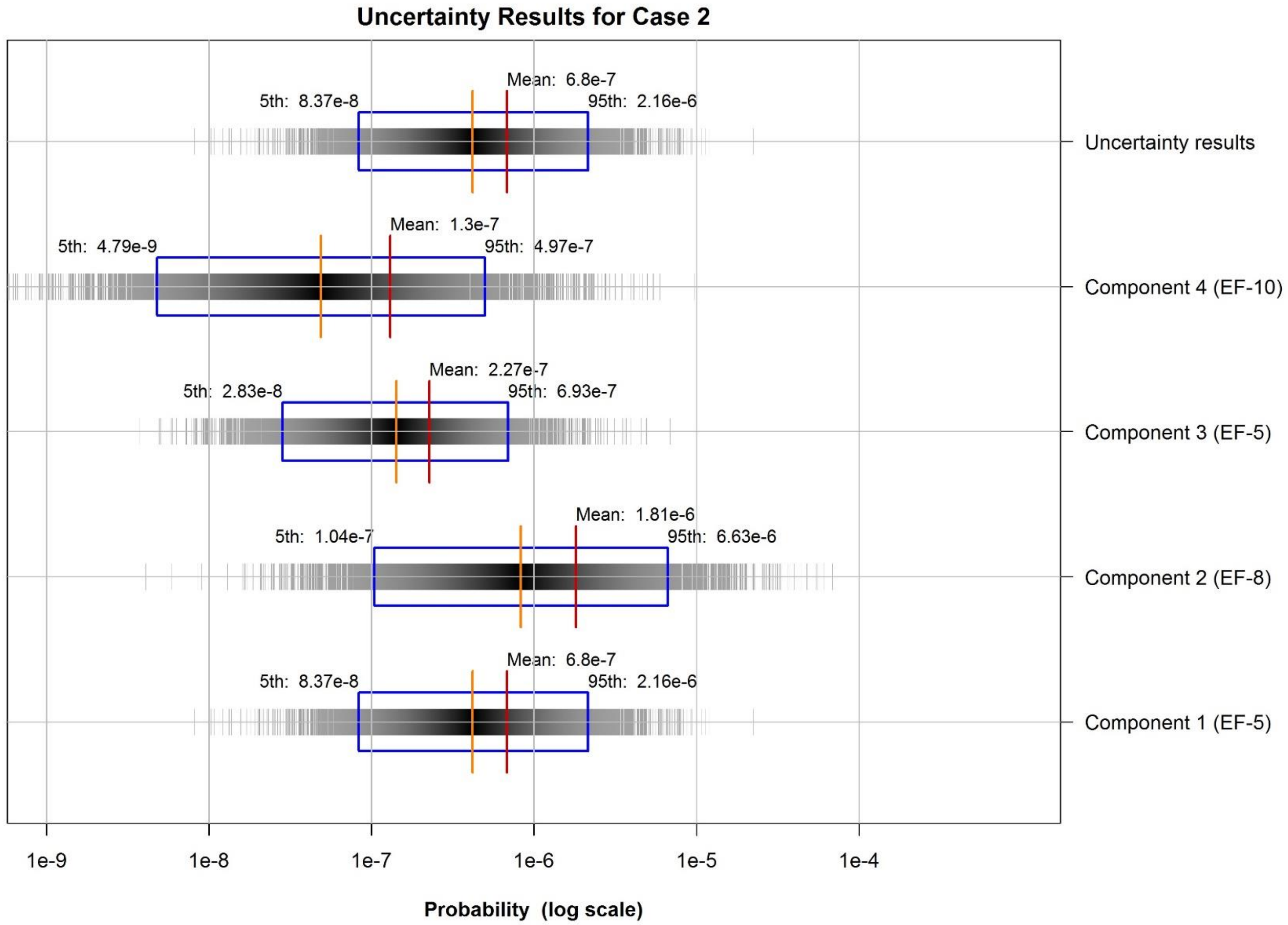
- Model Error Factor (EF) = 95^{th}/ Median = 16.2

Case Study
Uncertainty-Importance Analysis

- The Uncertainty-importance routine identified component 1 as a major driver of the model uncertainty
- A data research on Component 1 yielded more applicable data
  - Found historical data for a like component from the aerospace industry

- rbd_case_study OR RAM VIII 2015
  - COMPONENT1 (4.170E-007) Source: Aerospace Historical
  - components_in_series AND
    - COMPONENT2 (8.354E-007) Source: Piece Part Count
    - COMPONENT3 (1.390E-007) Source: Aerospace Historical Data for same component
    - COMPONENT4 (4.865E-008) Source: Non-Expert Judgement (documented)

Case Study
Uncertainty Quantification Results
Run2



- Model Error Factor (EF) = 95th/ Median = 5.6

Conclusion

- Higher data applicability improves certainty of estimates
- Uncertainty represents the spread of the parameter estimate. How confident are we that the estimate is correct
  - Useful for decision makers
  - Communicates credibility or lack of it
- Adjustments for environments with k factors is another source of uncertainty
- Highly applicable data in the model ensures lower uncertainty
  - Crucial step that increases the confidence level of the components and subsequent uncertainty estimate
- Uncertainty-Importance routines can prioritize the need to collect additional parameter data

Questions?

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